XMM-Newton Observations of the Isolated Neutron Star 1RXS J214303.7+065419 / RBS 1774

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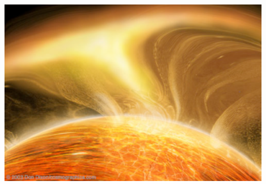

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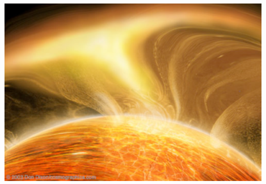
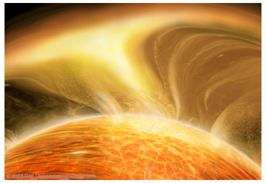
[update of the work reported in Zane et al. (2005) *ApJ*, 627, 397]



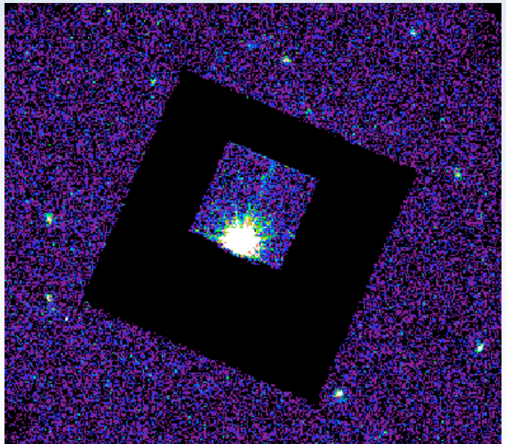
Background

- RBS1774 (1RXS214303.7+065419) is the seventh X-ray emitting, dim, isolated neutron star (XDINS), medium age (~10^5–10^6 year)
- X-rays from XDINS are from the neutron star surface: important for
  - examining thermal and magnetic surface properties
  - tracking evolutionary status of the neutron star
- Discovered by Zampieri et al (2001) in *ROSAT* PSPC pointing of BL Lac MSS 2143.4+0704; also seen in RASS
- *ROSAT* data indicated a soft X-ray spectrum to which a blackbody of *kT*~92 eV was an acceptable fit
- No plausible optical counterpart seen down to R~23
  $\Rightarrow$ X-ray:optical flux ratio of $>10^3$

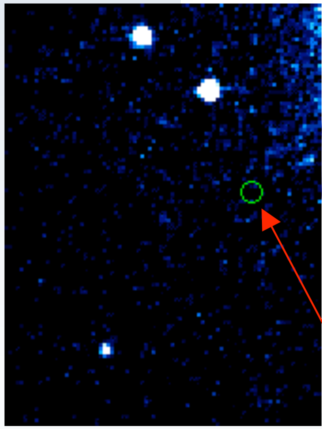


Observations of RBS1774

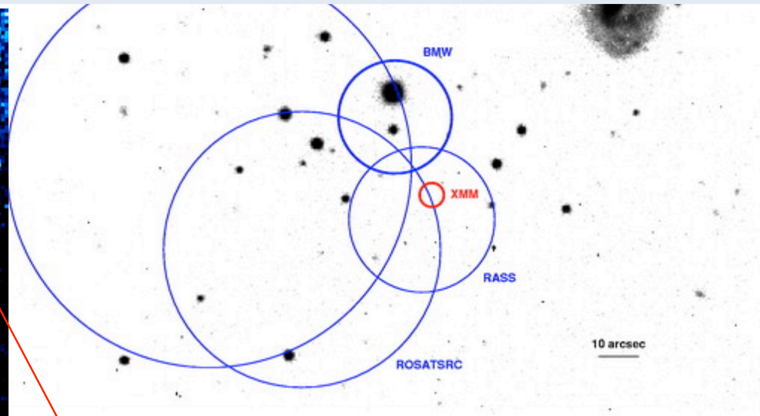
- Observations were taken on 2004 May 31 with *XMM-Newton* in small window mode, with thin filter, and with 23 sec total exposure time after GTI selection; standard reductions with SASv6.0.0 for off-axis position
- New source position corrects the previous uncertain *Rosat* positions with a 90% uncertainty radius of 3 arcsec (α $21^h43^m03.3^s$, δ $+6°54'17''$)



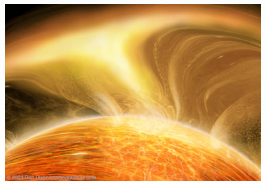
EPIC combined image



no detection in *XMM*-OM 280nm image

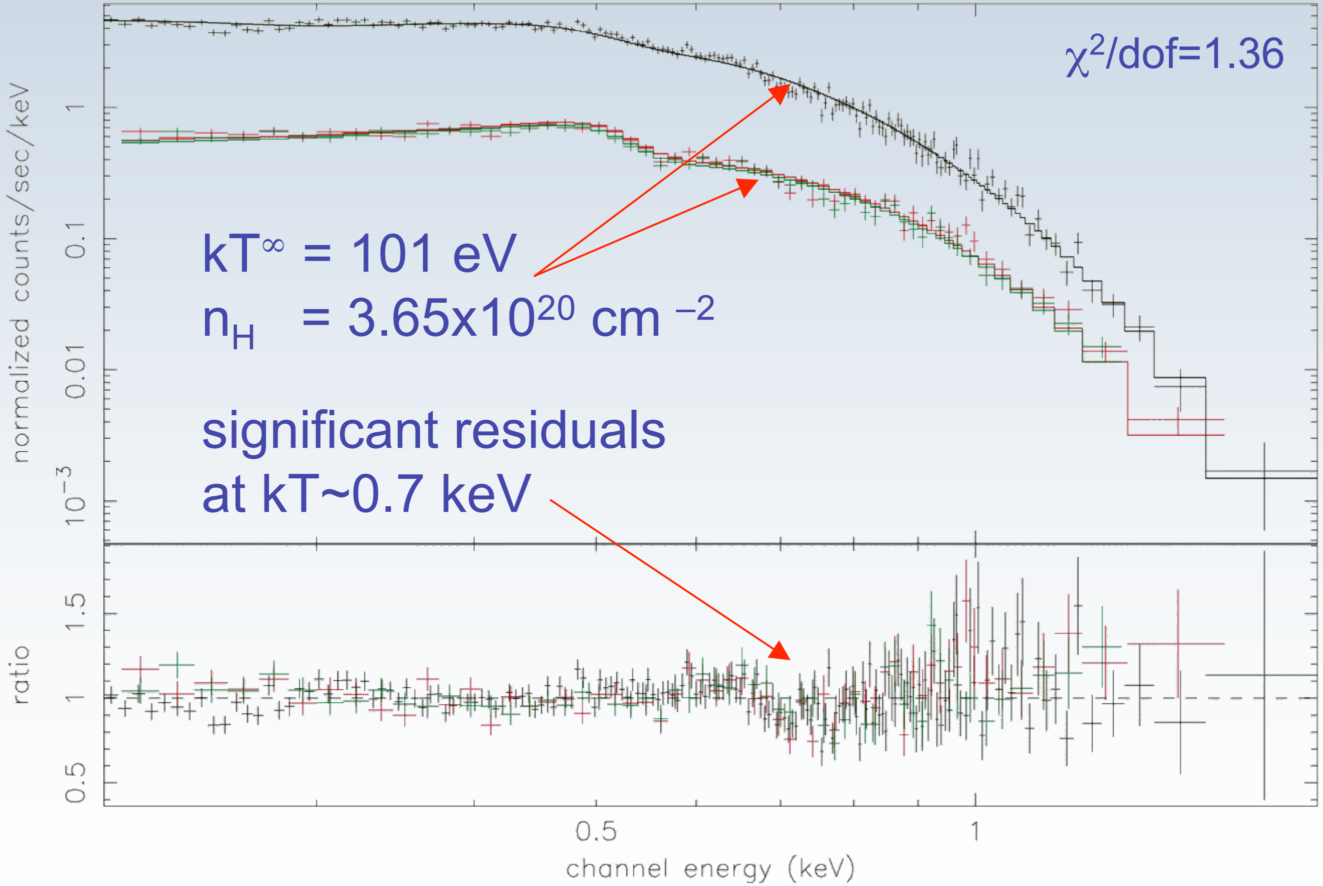


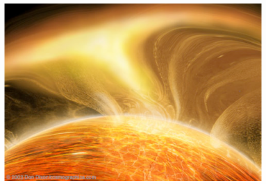
ESO NTT R-band image



Spectral Analysis: EPIC data

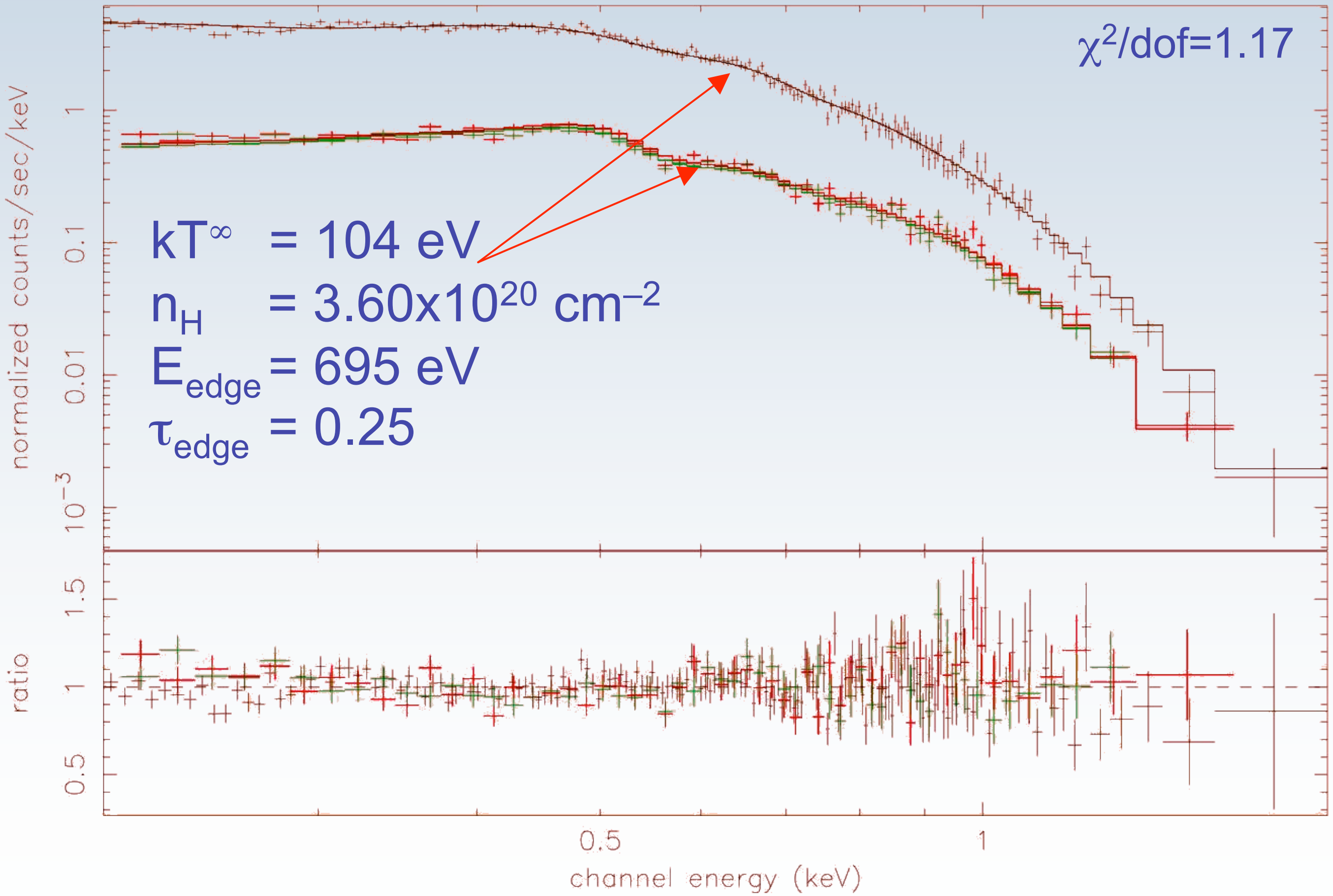
- simultaneous pn+MOS fit to cold absorber + blackbody:

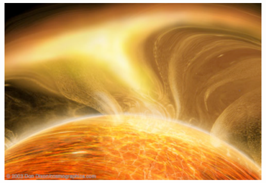




Spectral Analysis: EPIC data

- Addition of an edge at 0.7keV removes residuals: significantly improved fit





Spectral Analysis: model fits

- For completeness: model fit parameters

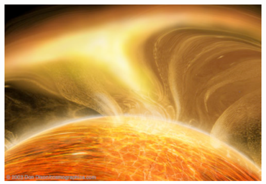
Model-Fit Parameters: Blackbody (bb) Model

Model	n_H (10^{20} cm^{-2})	kT_{bb}^{∞} (eV)	$E_{edge/line}$ (eV)	τ_{edge}; τ_{line}	σ_{line} (eV)	f_X[a] (ergs cm^{-2} s^{-1})	χ^2/dof
bb..	$3.65^{+0.16}_{-0.13}$	$101.4^{+0.5}_{-0.6}$	...	...	...	5.16×10^{-12}	1.36
bb + absorption edge..................	$3.60^{+0.21}_{-0.16}$	$104.0^{+0.6}_{-0.7}$	694^{+5}_{-11}	$0.25^{+0.03}_{-0.03}$	...	5.07×10^{-12}	1.17
bb + Gaussian line......................	$3.74^{+0.14}_{-0.10}$	$102.1^{+0.5}_{-0.3}$	754^{+8}_{-9}	$4.8^{+1.0}_{-0.5}$	27^{+15}_{-8}	5.20×10^{-12}	1.20

- No improvements with a power law or 2nd blackbody
- Also fits to atmospheric models (NSA in XSPEC): fits worse

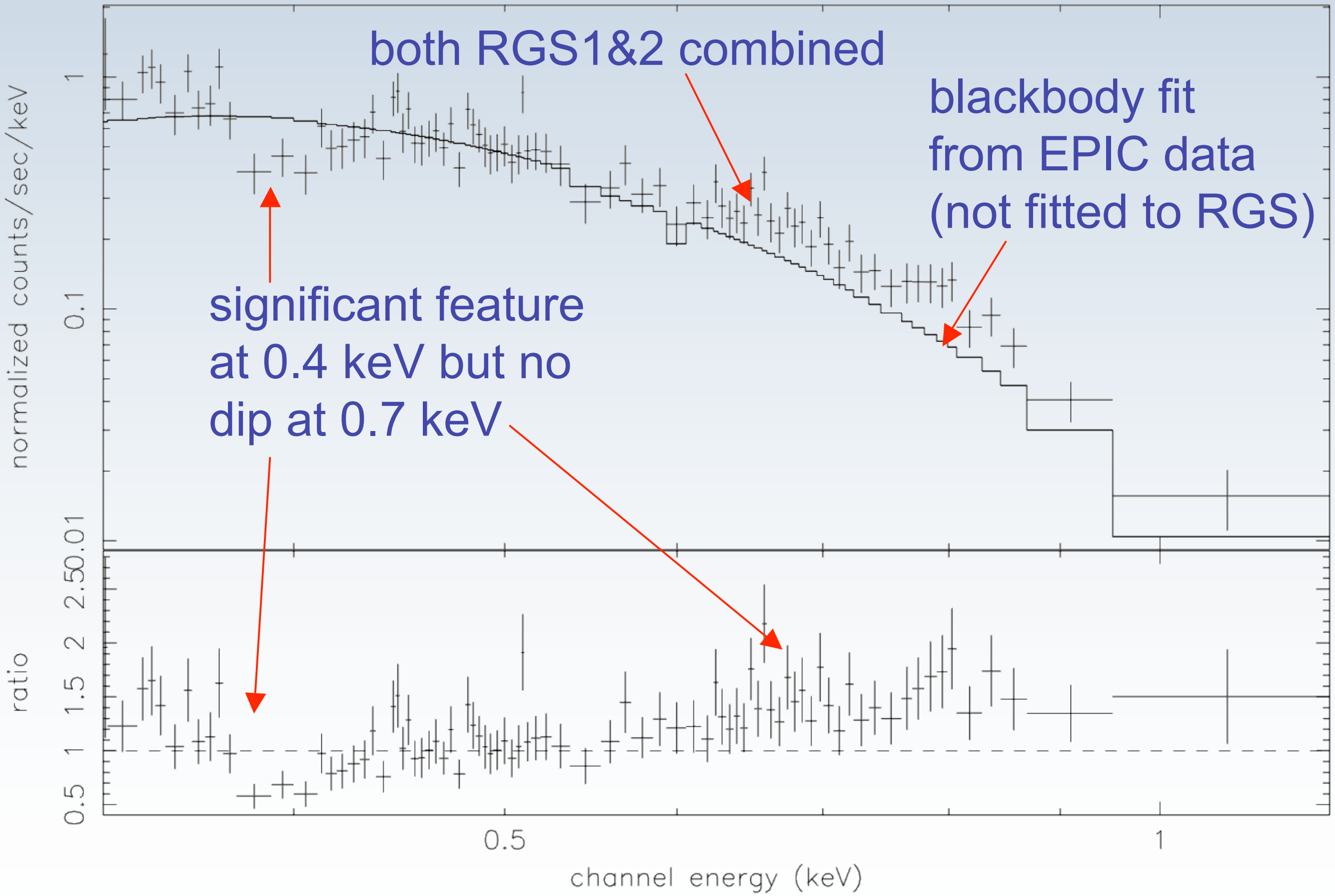
Model-Fit Parameters: Atmospheric Models

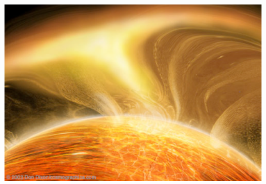
B (10^{12} G)	n_H (10^{20} cm^{-2})	kT^{∞} (eV)	χ^2/dof
0..	$8.4^{+0.3}_{-0.2}$	$29.8^{+0.3}_{-0.3}$	1.94
1..	$8.3^{+0.2}_{-0.2}$	$47.3^{+0.5}_{-0.4}$	1.99
10..	$8.6^{+0.1}_{-0.2}$	$50.0^{+0.4}_{-0.4}$	2.19



Spectral Analysis: RGS data

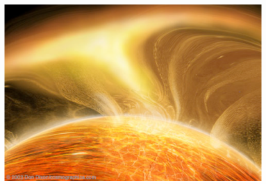
- Source faint in RGS, but still sufficient for spectral analysis





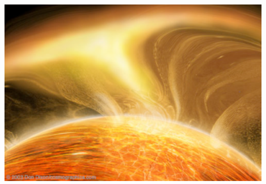
Spectral Analysis: summary

- Main features of spectrum are clear:
  - single blackbody spectrum with *kT*~102 eV most favoured by fits
  - no power law component
- Situation unclear with respect to line features:
  - EPIC fits require absorption edge/line at 0.7 keV (statistically significant) and no line at 0.4 keV
  - RGS indicates absorption edge/line at 0.4 keV (apparently statistically significant) and no line at 0.7 keV
- At these low RGS countrates calibration is not likely to be the problem
- No calibration features at EPIC 0.7 keV seen in other good S/N spectra
- For the present, line features in RBS1774 should be regarded as unconfirmed until longer RGS observations are made

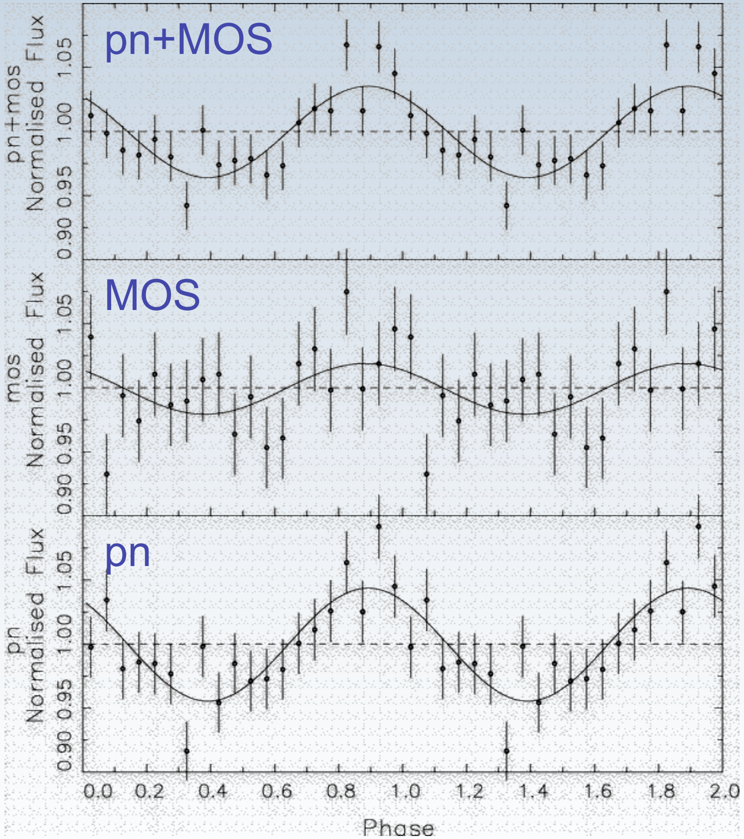


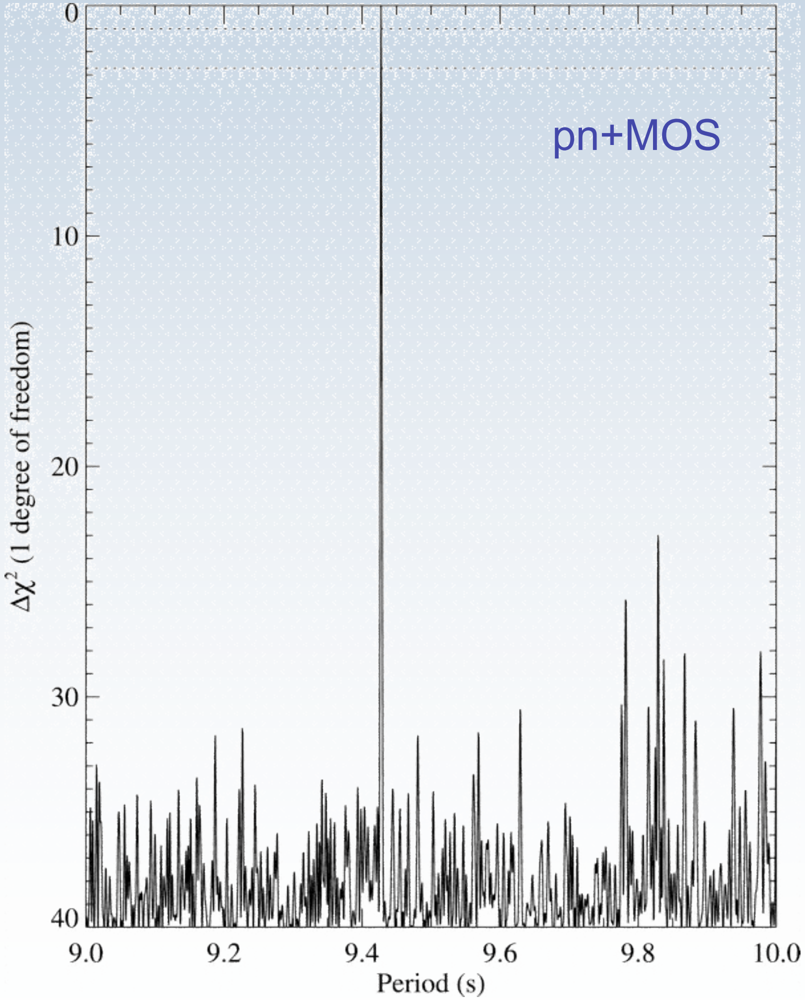
Timing Analysis

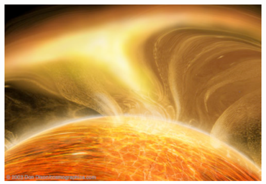
- EPIC pn and MOS event files were analysed using a maximum likelihood periodogram technique (Zane et al 2002, Cropper et al 2004).
- Periods searched from 10 ksec to 30 msec
- Period found at 9.437 sec, 6σ above the noise; evident independently within both pn and MOS data with consistent phasing
- Including random probability of peaks in the 1-1000 sec interval, the peak is significant at 4σ
- Semi-amplitude of variation is 0.036±0.006 (*i.e.* ~4%) from sinusoidal fits to the data folded on the 9.437 period



Timing Analysis: periodogram and folded data

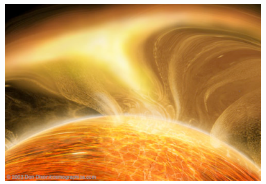






Discussion: spectral features

- We interpreted the 0.7 keV line as either
  - proton cyclotron line with $B \sim 1.4\text{x}10^{14}$ G
  - H ionisation edge (Ho et al 2003) or He bound-bound transitions (Sanwal et al 2002, Zavlin et al 2004) again giving $B \sim$ few $\text{x}10^{14}$ G or
  - electron cyclotron line giving $B \sim 7.5\text{x}10^{10}$ G
  - atomic transition of a mid-Z H-like ion (eg CVI, NVII, OVIII) giving $B \sim 10^{11}$ G
- If this line is real (or if RGS, halve for 0.4 keV), then fields are either
  - magnetar like (similar to XDINS RX J1605.3+3249 & RX J0806.4–4123)
  - or *less than* those in normal radio pulsars



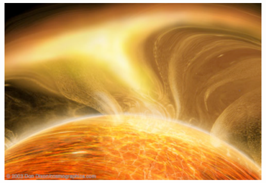
Discussion: comparison with other XDINS

- XDINS all have *kT* ~ 50-100 eV, periods (if any) of ~ 10 sec
- Most have lines <1 keV (<500 eV without RBS1774)

Source	kT_{bb}^{∞} (eV)	n_H (10^{20} cm^{-2})	E_{line} (eV)	P (s)	Semiamplitude[a]	Reference
RX J1856−3754	56.7	0.18	No	No	No	1
RX J0720−3125	85.2	1.38	270	8.39	11%	2
RX J1605.3+3249	94.1	0.68	493	No	No	3
RX J1308.6+2127	85.8	4.10	290	10.31	18%	4
RX J0420−5022	44.9	1.02	329	3.45	13%	5
RX J0806−4123	95.6	0.41	$\boxed{460}$	11.37	6%	5
RBS 1774	101.4	3.65	700	9.44	4%	6

[a] Semiamplitude of the folded light curve.

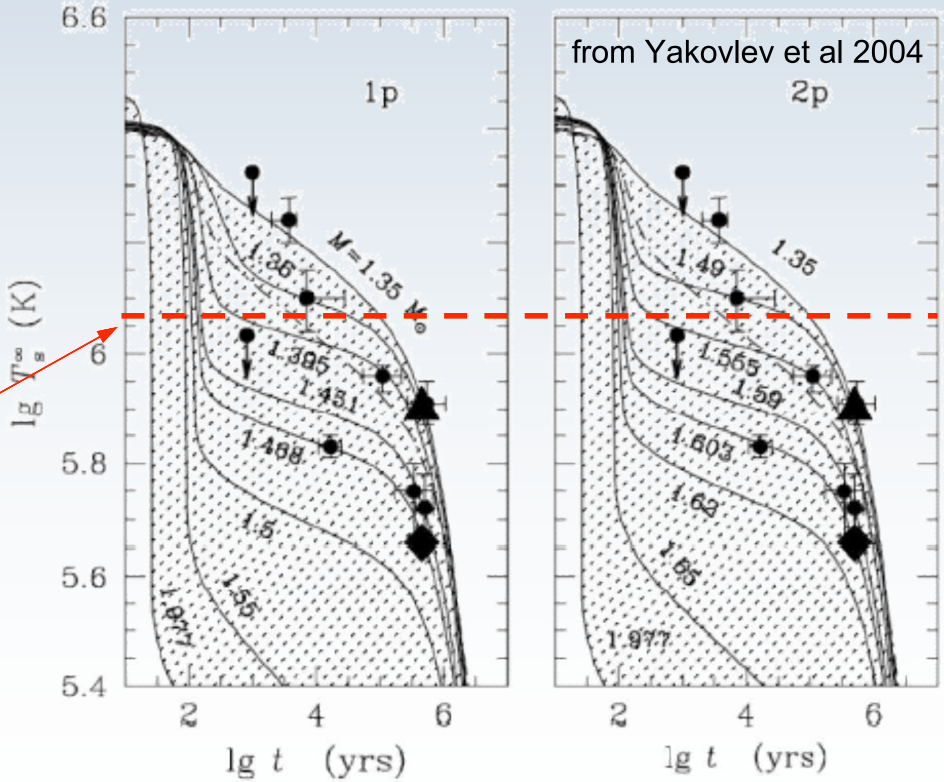
References.—(1) Burwitz et al. 2003; (2) Haberl et al. 2004a; (3) Van Kerkwjik et al. 2004; (4) Haberl et al. 2003; (5) Haberl et al. 2004b



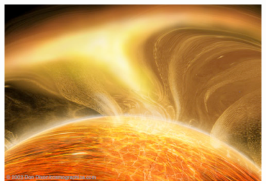
c.f. also eg Haberl (2005)

Discussion: cooling age

- RBS1774 is therefore the hottest of the XDINS
- Cooling age from cooling models with proton superfluidity (Yakovlev et al 2004) is
  10^5 years for $M_{NS} = 1.35\ M_\odot$
  10^4–10^5 years for $M_{NS} = 1.4\ M_\odot$
  10^2–10^5 years for $M_{NS} = 1.5\ M_\odot$
  10^2 years for $M_{NS} = 1.6\ M_\odot$
  depending on different models



RBS1774



Discussion: magnetic field decay age

- *If* RBS1774 has a high magnetic field, its age τ_d can also be computed from the field decay time using the equations in Cropper et al (2004)

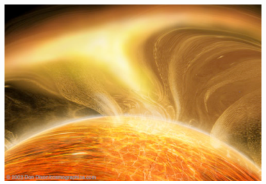
$$B_0 = \left(P\dot{P}\right)^{1/2}\left[b^{\frac{\alpha-2}{2}} - \frac{\alpha-2}{2}\frac{a}{b}\left(P\dot{P}\right)^{\frac{\alpha-2}{2}}\left(P^2-P_o^2\right)\right]^{\frac{1}{2-\alpha}}$$

$$\tau_d = \left(a\alpha B_0^{\alpha}\right)^{-1}\left\{\left[1-\frac{2-\alpha}{2}\frac{a}{bB_0^{2-\alpha}}\left(P^2-P_o^2\right)\right]^{\frac{\alpha}{\alpha-2}} - 1\right\}$$

  where $\dot{P} \sim 10^{-12}$ s s^{-1} can be estimated from dipole radiation and the current spin period of 9.437 sec, α and *a* depend on the model (Hall cascade and ambipolar diffusion – Colpi et al 2000) and *b*~3

- If the field decay is by
  - Hall cascade then $\tau_d \sim 10^4$ yr
  - Ambipolar diffusion then $\tau_d \sim 10^5$ yr

- Field decay and thermal ages are consistent for $M_{\rm NS}$ = 1.35-1.5 $M_\odot$



Summary

- From *XMM-Newton* observations, RBS1774 has a 0.1 keV thermal spectrum and a spin period of 9.437 sec with a low amplitude (4%) sinusoidal X-ray variation
- A power-law component can be excluded. Neutron star atmosphere models (as in Zavlin et al 1996) do not provide good fits.
- The EPIC data require a line/edge at 0.7 keV; however this is not seen in the RGS data, which instead has a feature at 0.4 keV: it is not clear how to resolve this inconsistency.
- Cooling models predict ages of 10^5 yr for 1.35 $M_\odot$ – 10^5 yr for 1.6 $M_\odot$
- If the magnetic field is magnetar-like (as probably required by either line), then the age from field decay is 10^4 – 10^5 yr; masses are consistent with the cooling age for 1.35 – 1.5 $M_\odot$